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Application of Entropy Weighted Water Quality Index and Physicochemical Indices to Evaluate Groundwater Quality in Damghan Plain

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ABSTRACT

In this study, the Entropy Weighted Water Quality Index (EWQI) was used to assess the groundwater suitability for drinking purposes in Damghan Plain, Iran. This index has been known as the most unbiased model for assessing drinking water quality. Additionally, physicochemical indices including Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Kelley's Ratio (KR), Salinity Hazard (SH), Synthetic Harmful Coefficient (K), Potential Salinity (PS), Total Dissolved Solids (TDS), Chloride (Cl^-), Permeability Index (PI) and Soluble Sodium Percentage (SSP) were used to evaluate the suitability of groundwater for irrigation purposes at August 2018 (dry season) and February 2019 (wet season). The results indicated that sodium (Na^+) and chloride (Cl^-) are exceeding the permissible limits based on WHO standards and Cl^- has the highest entropy weight. EWQI maps illustrated that the groundwater has moderate quality in the western parts and poor quality in the eastern parts of the study area. The mean value of this index has decreased from 149.47 in August 2018, to 147.26 in February 2019, which reflects that the groundwater quality has been improved for drinking purposes. The values of SAR, KR, PI and SSP indices slightly increased, which indicated that the quality of groundwater has more deteriorated in terms of these indices. The mean value of MH, SH, K, PS, TDS and Cl^- indices have slightly decreased during the study period. Finally, Land Use-Land Cover (LULC) map was used to show which groundwater consumption is appropriate with its quality. Groundwater in the urban areas has moderate and poor quality for drinking purpose and suitable quality in terms of SAR, K and PI and unsuitable in terms of MH, KR, SH, PS, TDS, Cl^- and SPP in agricultural lands. The suitable condition in terms of SAR, K and PI is because of the high concentration of Mg^{2+} and Ca^{2+}. Thus, groundwater is not suitable for irrigation in the agriculture sector.

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1. Introduction

Today, water resources play a vital role in economic, social developments and quality of life across the world. Human activities such as urbanization, and agricultural and industrial development are deteriorating the quality of these resources (Oki and Akana, 2016). However, decreasing water quality is one of the most important problems in recent century (Nair *et al*., 2015; Li *et al.,* 2017).

In arid and semi-arid regions, groundwater resource is the most important source of fresh water for various requirements such as human consumption, agricultural and industrial purposes, due to lacking rainfall and surface water. Population growth and increasing use of these resources have caused depletion in groundwater levels and decreased its quality for various agricultural purposes (Asghari Moghaddam and Vadiati, 2016). Additionally, groundwater and its effects on humans' health and development are closely related in these regions. Therefore, if its quality is poor, caused by excessive application of fertilizers for instance, humans' health will be in danger (Pei-Yue *et al*., 2010) and this dependency has increased in the recent decades (Adimalla, 2020). Thus, this is the reason for a comprehensive assessment of the quality of groundwater for proper management of this important resource.

The groundwater quality is determined by some parameters from physical, chemical and biological aspects (Schriks *et al*., 2010). The concentration of some physicochemical parameters can affect its suitability for drinking, irrigation and industrial purposes. Therefore, it is necessary to be aware of the physical and chemical composition of groundwater to evaluate its usefulness for various purposes (Venkateswaran *et al*., 2011). Analyzing groundwater is important to employ a groundwater resource management strategy. Mapping spatial variation of various physicochemical compositions is essential to correctly develop the groundwater schemes and management, consequently (Manoj *et al*., 2017).

Various methods have been used to evaluate the quality of water over time. Traditional methods are often qualitative and cannot accurately describe its quality (Asghari Moghaddam and Vadiati, 2016). However, new water quality assessment methods have been increased, recently. One of the common methods for drinking purposes is Water Quality Index (WQI). This index is a numerical way to determine the suitability of water (Amiri et al., 2014) and considered in many parts of the world, due to its high capability in expressing water quality information and application of important and effective parameters in the evaluation of water quality (dos Santos Simões et al., 2008). A necessary step in this method is to assign a weight of each parameter which is determined by experts based on their experience, knowledge and discretion (Amiri et al., 2013). Therefore, assigning a correct weight for each parameter is required to take the maximum advantage of this index. There are various ways to determine the weight of the parameters, such as the entropy method. In this method, the weight of parameters determine based on their concentration and shows the relative importance of parameters in groundwater quality. This method provides the most unbiased, justifiable, accurate, and reliable analysis of groundwater quality. Combining WQI with the entropy method is a way to reduce the subjectivity errors while assigning the weight of water quality parameters (Peiyue et al., 2010). Entropy Water Quality Index (EWQI) is a model which provides unbiased, accurate and reliable analysis of groundwater quality by determining a suitable weight for each water quality parameter (Feng et al., 2019; Singh et al., 2019; Wang et al., 2019; Maskooni et al., 2020; Ukah et al., 2020;).

In terms of irrigation purposes, the water quality is supposing a significant necessity with the rising pressure on agriculture (Wijnen *et al*., 2012). For adopting a suitable plan for agricultural lands, an adequately understand the properties of water is needed and measurement of physicochemical parameters in water reservoir is necessary to achieve this aim. There are various indices to evaluate the quality of water, such as Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Kelley's Ratio (KR), Salinity Hazard (SH), Potential Salinity (PS), Sodium Percentage (Na%) and Permeability Index (PI) which are widely used over the world (Sharma *et al.*, 2017; Ememu and Nwankwoala, 2018; Jain and Vaid, 2018; Ghazaryan *et al.*, 2019; He *et al.*, 2019; Kahsay *et al.*, 2019; Kumari and Rai, 2020; Singh *et al.*, 2020).

Damghan Plain, Iran, is located in an arid region and surface water is limited, so the major source of fresh water is groundwater. Therefore, groundwater, as the only source of clean water, needs to be well-used. Thus, in the present study, the suitability of groundwater quality in Damghan Plain for drinking uses has been assessed by EWQI, as well as for the agricultural purposes using physicochemical characteristics and indices through GIS. Combining the groundwater data with GIS can provide suitable and effective results of groundwater conditions. As Damghan Plain has limited surface water resources, groundwater is the main freshwater resource, and it is essential to investigate the groundwater quality for proper management, thus in the present study the groundwater in this plain has been evaluated.

2. Materials and methods

2.1. Case Study

Damghan Plain is located in Semnan province between 35° 51' and 36° 09' latitude and 54° 04' and 54° 26' longitude, with an area of 732.51 km^2. It is located in the south of the Alborz mountain range and north of the Kavir desert with an arid and semi-arid climate (Arabameri *et al.*, 2019). The average temperature is 15.8 °C and the long-term annual average of precipitation is about 151 mm (Ashtiani *et al.*, 2016). The elevation varies from 1309 meters (a.s.l.[1]) in the northwest to 1047 meters (a.s.l.) in the southeast. This plain, like other arid and semi-arid regions, is facing with water problem. The water supply is mostly through the groundwater resources (Parhizkar *et al.*, 2015) which are mainly used for the agricultural purposes. Fig 1 shows the study area and location of piezometers and quality monitoring wells in Iran.

2.2. Methodology

In this study, nine physicochemical parameters, including Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sulfate (SO_4^{2-}), Chlorine (Cl^-), Bicarbonate (HCO_3^-), Potential of Hydrogen (pH), Total dissolved solids (TDS), Electrical Conductivity (EC), and were used from 21 groundwater samples in Damghan Plain in August 2018 and February 2019. The data of groundwater quality were obtained from the Iran Water Resources Management Company. In Damghan Plain agricultural activities are started in February (wet season) and finished in August (dry season) and the groundwater is used during these activities and charged during the autumn season.

The quality of groundwater assessed for suitability in drinking adopting EWQI and agricultural purposes using physicochemical indices namely Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Kelley's Ratio (KR), Salinity Hazard (SH), Synthetic Harmful Coefficient (K), Potential Salinity (PS), Total Dissolved Solids (TDS), Chloride (Cl^-), Permeability Index (PI) and Soluble Sodium Percentage (SSP) based on groundwater data.

In order to generate the maps of adopted indices, Inverse Distance Weighted (IDW) interpolation technique was employed in ArcMap 10.7. This technique is widely used by many researchers to assess the spatial distribution of groundwater physicochemical parameters (Kawo and Karuppannan, 2018; Rostami *et al.*, 2019; Gnanachandrasamy *et al.*, 2020; Verma *et al.*, 2020; Zolekar *et al.*, 2020). In this interpolation technique, the value of un-sampled cells is calculated using surrounding points (Prasanth *et al.*, 2012).

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[1] Above sea level

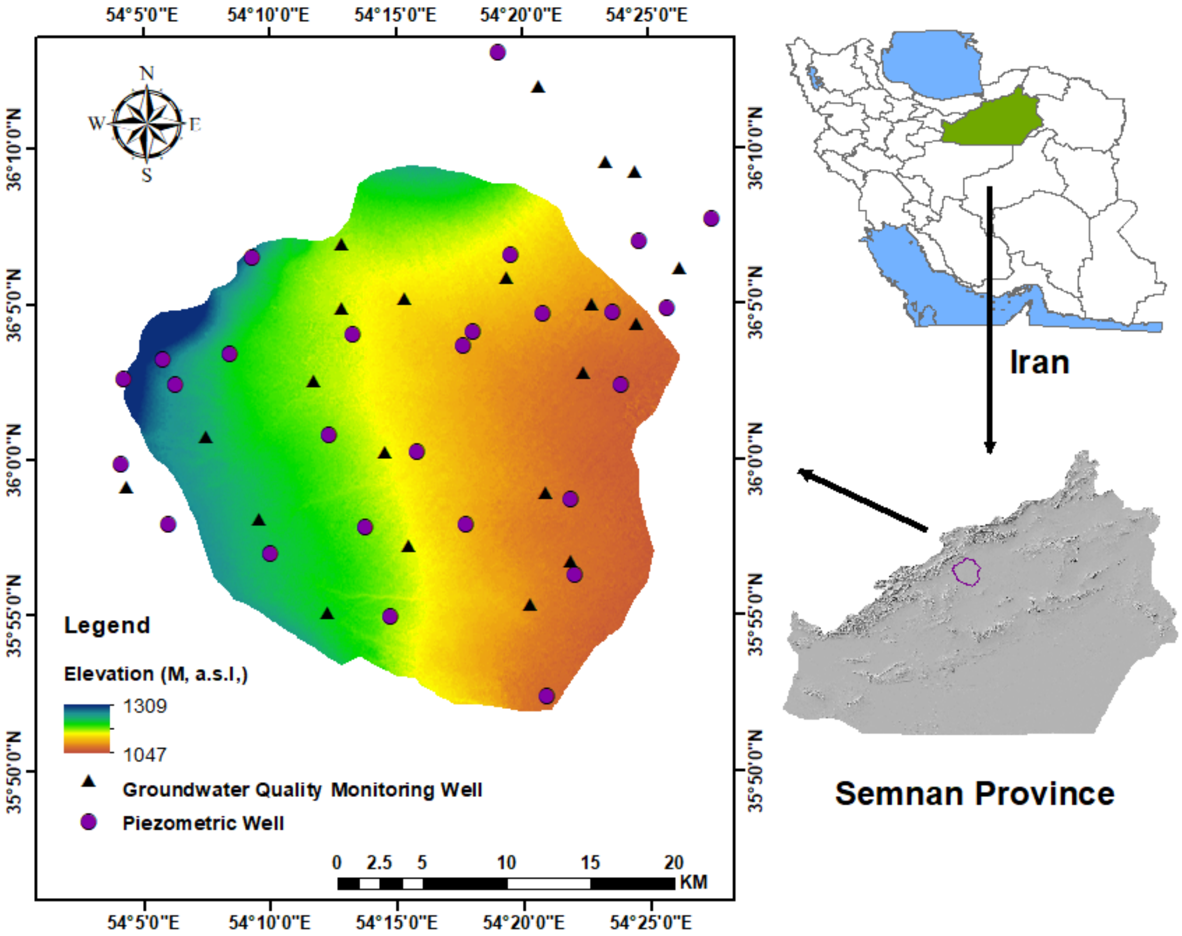

Fig. 1. Study area and location of piezometers and quality monitoring wells

2.2.1. Entropy Weighted Water Quality Index

WQI is widely used for evaluating groundwater suitability for drinking purposes, which its quality depends on physicochemical parameters (Liu *et al*., 2020). In calculation of WQI, the weights of each parameter are usually determined based on expert opinion, but recently, entropy theory has been used to compute the weight of water quality parameters (Egbueri *et al*., 2020; Maskooni *et al*., 2020; Ukah *et al*., 2020; Adimalla, 2021;). In this study, EWQI, which is presented by Pei-Yue *et al*. (2010), was used to assess the groundwater quality for drinking purposes. The concept of entropy was initially proposed by Shannon (1948) which expresses the uncertainty degree of a stochastic event (Amiri *et al*., 2014), or in other words, it shows how much an event can be stochastic (Gorgij *et al*., 2017).

EWQI provides an unbiased assessment of water quality considering all the measured parameters (Ukah *et al*., 2020) and its calculation is done in three steps including: calculating entropy weight, quality rating scale for each parameter and classification of the groundwater quality. In the first step, the performance matrix is constructed. The matrix (X) indicates a summary of physicochemical analysis data, as m ($i = 1, 2, \ldots, m$) denotes the number of wells that are monitored to assess groundwater quality based on n ($j = 1, 2, \ldots, n$) measured parameters. Thus, x_{ij} is the value of j^{th} parameter in the ith well.

Then, according to the analyzed data, matrix X can be constructed as follows:

$$\mathrm{X} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

Since the groundwater quality parameters have different units, the normalized matrix will be computed using the efficiency type normalizing function as (Pei-Yue *et al.*, 2010);

$$y_{ij} = \frac{x_{ij} - (x_{ij})_{min}}{(x_{ij})_{max} - (x_{ij})_{min}} \tag{2}$$

Where x is the value of *j*th parameter in the *i*th well and $(x_{ij})_{max}$ and $(x_{ij})_{min}$ are the maximum and minimum values of *j*th parameter, respectively.

Then, the *Y* (normalized) matrix will be constructed as:

$$\mathrm{Y} = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & & y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \tag{3}$$

The *j*th parameter index amount, in i^{th} sample is calculated as;

$$P_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \tag{4}$$

Where *m* represents the number of wells. In the next step, the entropy value of parameter *j* is computed as follows;

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} P_{ij} \,.\, \ln P_{ij} \tag{5}$$

The less the value of e_j is, the more effect the *j* index will have (Pei-Yue *et al.*, 2010). The following step is to calculate the entropy weight for each parameter as;

$$w_i = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)} \tag{6}$$

The second step to determine EWQI value is to compute the quality rating scale (q_i) for each parameter in every sample as;

$$q_{i} = \left(\frac{C_i}{S_i}\right) \times 100 \tag{7}$$

Where C_i is the concentration of each physicochemical parameter in each groundwater sample in *mg/L* except for pH which is defenseless and S_j is the standard of each parameter based on World Health Organization (WHO) Standards (Table 1).

The third step is to calculate EWQI as following formula;

$$EWQI = \sum_{j=1}^{n} w_i \,.\, q_i \tag{8}$$

Where *n* is the number of groundwater quality parameters.

Table 1. Groundwater quality limitation for drinking purposes based on World Health Organization Standards (WHO, 2011)

Parameter	Unit	WHO Standard
Na^+	mg/L	200
Mg^{2+}	mg/L	50
Ca^{2+}	mg/L	75
SO_4^{2-}	mg/L	250
Cl^-	mg/L	250
HCO_3^-	mg/L	120
pH	-	6.5 – 8.5
TDS	mg/L	500

According to Pei-Yue *et al*. (2010), the groundwater quality based on EWQI is classified in five ranks for drinking purposes (Table 2).

Table 2. Groundwater quality ranking based on EWQI for drinking purposes

Groundwater quality	Rank	EWQI
Excellent drinking quality	1	< 50
Good drinking quality	2	50 - 100
Moderate drinking quality	3	100 – 150
Poor drinking quality	4	150 – 200
Extremely Poor drinking quality	5	200

2.2.2. Evaluation of Groundwater Quality for Irrigation Purposes

There are several parameters and indices for assessing the groundwater status for agricultural purposes, which provide comprehensive results to recognize the groundwater suitability for irrigation. In the present study, Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Kelly's ratio (KR), Salinity Hazard (SH), Synthetic Harmful Coefficient (K), Potential Salinity (PS), Total Dissolved Solids (TDS), Chloride (Cl^-), Permeability Index (PI) and Soluble Sodium Percentage (SSP) were adopted in order to assess the suitability of quality of groundwater for agricultural activities (Table 3). All the cations and anions are in *meq/L* to calculate these indices.

After determining the groundwater quality, Land Use-Land Cover (LULC) using Landsat OLI 8 images and groundwater level fluctuations map during the study period were generated for the study area to better understanding of the groundwater uses for various purposes. The methodology applied in this research is summarized in Fig 2.

3. Result

For assessing the groundwater suitability for drinking and irrigation purposes, physicochemical compounds of groundwater samples were measured. The statistical summary of the physicochemical of groundwater samples parameters are presented in Table 4.

Table 3. Groundwater quality indices for irrigation purposes

Index	Equation	References
Sodium Adsorption Ratio	$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+}+Mg^{2+})}{2}}}$	Ravikumar *et al.* (2011)
Magnesium Hazard	$MH = \frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})} \times 100$	Szabolcs (1964)
Kelley's Ratio	$KR = \frac{Na^{+}}{(Ca^{2+}+Mg^{2+})}$	Kelley (1963)
Salinity Hazard	$SH = EC\ (\mu S/cm)$	Tahmasebi *et al.* (2018)
Synthetic Harmful Coefficient	$K = 12.4 \times TDS + SAR$	Zhou *et al.* (2009)
Potential Salinity	$PS = Cl^{-} + \frac{SO_4^{2-}}{2}$	Doneen (1962)
Total Dissolved Solids	$TDS\ (mg/L)$	Davis and DeWiest (1966)
Chloride	$Cl^{-}\ (meq/L)$	Stuyfzand (1989)
Permeability Index	$PI = \frac{(Na^{+}+\sqrt{HCO_3^{-}})}{(Na^{+}+K^{+}+Ca^{2+}+Mg^{2+})} \times 100$	Doneen (1964)
Soluble Sodium Percentage	$SSP = \frac{Na^{+}}{Na^{+}+Mg^{2+}+Ca^{2+}}$	Wani *et al.* (2014)

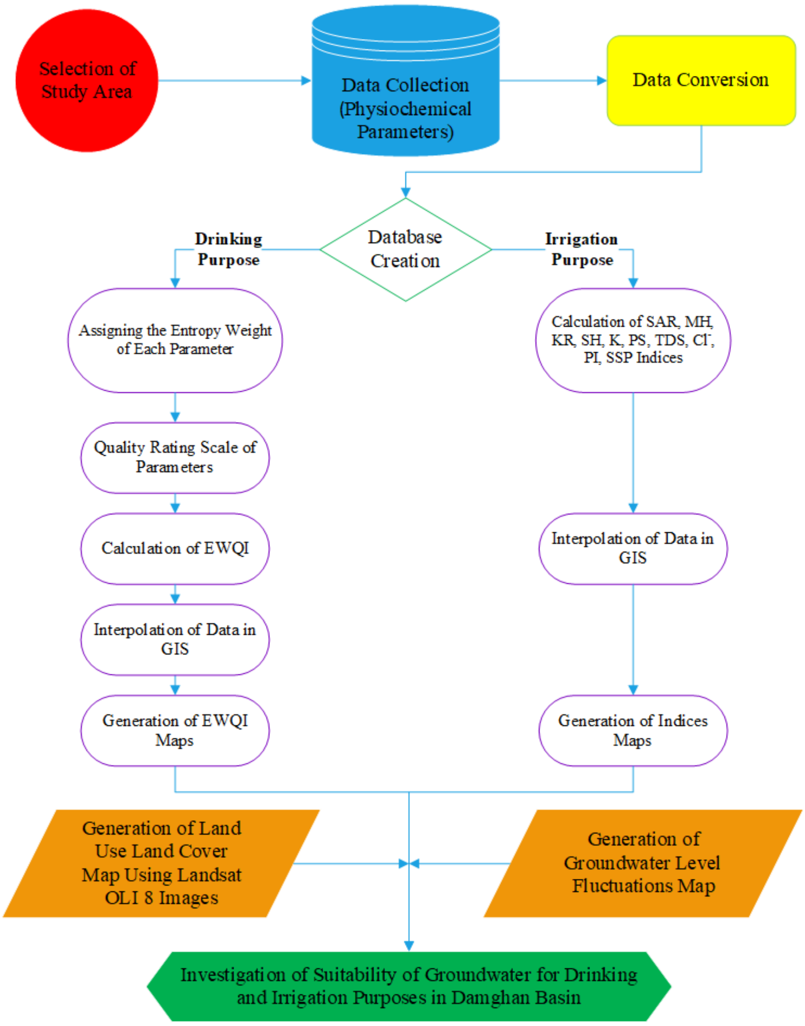

Fig. 2. Flowchart of the adopted methodology

Table 4. Statistical summary of physicochemical parameters

Parameter	Unit	Minimum	Maximum	Mean	Standard Deviation
Na^+	mg/L	168.29	533.37	301.48	73.32
Mg^{2+}	mg/L	35.24	125.15	57.60	16.08
Ca^{2+}	mg/L	48.10	166.33	80.83	23.13
SO_4^{2-}	mg/L	109.99	403.93	232.41	85.26
Cl^-	mg/L	328.98	917.45	451.68	113.24
HCO_3^-	mg/L	125.10	326.46	226.28	62.08
pH	-	7.14	7.95	7.61	0.22
TDS	mg/L	1022.00	2600.00	1379.05	282.86
EC	µmhos/L	1532.00	3930.00	2070.57	428.36

3.1. Geochemical Characterization of Groundwater

3.1.1. Ions Concentration

Statistically investigation of the ions results in each sample is necessary to realize groundwater conditions. Based on mean value of cations and anions, the order of cations is followed by $Na^+ > Ca^{2+} > Mg^{2+}$ and the anions are ordered as $Cl^- > HCO_3^- > SO_4^{2-}$. Na^+ and Cl^- have the most concentrations, compared to other cations and anions. So high concentration of these ions increases the salinity of groundwater, so that gives salty taste to it and has the greatest effect on the high values EC. Also, high concentration of sodium can cause high blood pressure in humans as well as kidney and heart disease. It has been reported by Ehteshami (*et al*., 2015) as well. Parhizkar (*et al*., 2015) reported that the main agricultural product in the region is pistachios, which can be due to the high concentration of these ions and high salinity in groundwater. The standard deviation of pH was 0.22 which indicates that its value does not change too much all over the plain. Maximum and minimum values of TDS exceeded standard value (Table 1), which its high value could be due to water-rock interaction (mineral dissolution) and evaporation (Xu *et al*., 2019).

Correlation analysis of physicochemical parameters was applied to present the degree of relation of them. The results showed the highest correlation was between all cations and all anions, while, in terms of individual ions, Na^+ and Cl^- had the strongest correlation with a correlation coefficient of 0.629, and there were the least correlation between Ca^{2+} and SO_4^{2-} with a correlation coefficient of 0.001, approximately (Fig 3). The relationship between Ca^{2+} and SO_4^{2-} indicates that gypsum is not a primary processes of groundwater chemistry (Chen *et al*., 2019) as well as, the weak relationship of $Ca^{2+} + Mg^{2+}$ and $HCO_3^- + SO_4^{2-}$ reflects that carbonates and sulfate cannot be dissolved in groundwater (Li *et al*., 2018). Totally, it can be said that, the hydrochemical process in the Damghan Plain are not influenced by one process and it is mainly influenced by several items including ions exchange, ions concentration and evaporation.

3.1.2. Durov Diagram

Durov diagram is employed in order to display a useful relationship for groundwater samples having similar physicochemical parameters compound. Durov diagram disclosed that cations were dominated by Na^+, while anions were dominated by Cl^- and there are not significant differences between the concentration of ions, TDS and pH values in both months August, 2018, and February, 2019. In the middle square, it is clearly observed that Na^+-Cl^- type is more dominant than other types. The values of pH, raged from 7.14 to 7.95 with an average of 7.61 which indicates that the groundwater has slightly alkaline nature and there are slight changes in the plain. TDS varied between 1022 and 2600 mg/L, with a mean value of 1379.05 (Table 4).

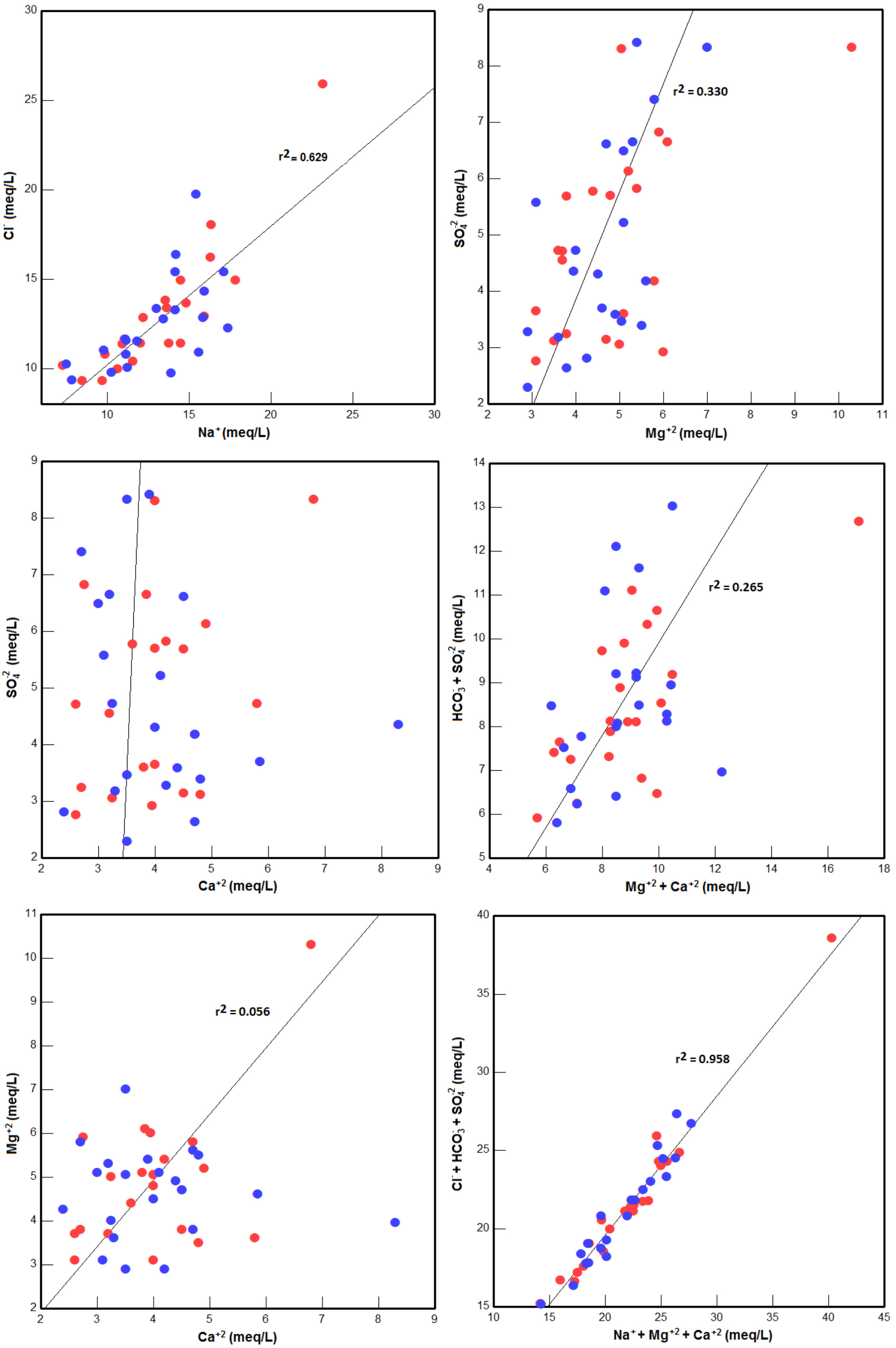

Fig. 3. Bivariate diagrams of ionic concentrations in groundwater samples (Red: August; Blue: February)

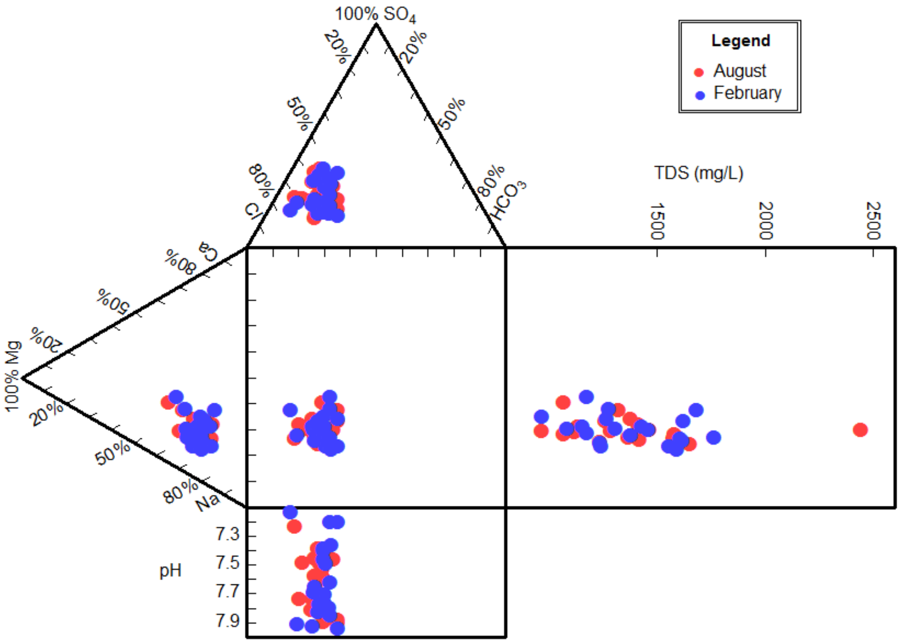

Fig. 4. Classification of groundwater samples based on Durov diagram

3.2. Entropy Weighted Water Quality Index

The most important step in computing EWQI is to determine the entropy weight, which is considered as a coefficient for calculating the WQI. Entropy weight of each parameter reflects the relative importance of that parameter in groundwater quality. A parameter with high entropy weight has little change in groundwater quality and has reached stability in the aquifer environment. Conversely, if the entropy weight of a parameter is low, its quality changes are high and it plays the major role in affecting groundwater quality.

After initial investigations, entropy weight was computed for each parameter. The higher the entropy weight of a parameter is, the greater the effectiveness of that parameter is. The results of parameters' entropy weight revealed that the effectiveness of the parameters follows $Cl^- > Mg^{2+} > SO_4^{2-} > TDS > Ca^{2+} > HCO_3^- > Na^+ >$ pH order, in August, 2018, while, in February, 2019, the order is as $Cl^- > SO_4^{2-} > Ca^{2+} > TDS > Mg^{2+} > HCO_3^- >$ pH $> Na^+$. As it is shown in Fig 5, Cl^- has the highest entropy weight among the parameters and there is no significant difference between them (with value of 0.176 in August and 0.173 in February). Therefore Cl^- has the most effect on groundwater quality in the study area.

After computing the entropy weight of parameters and water quality rating scale, based on the standards of the World Health Organization (WHO, 2011), the groundwater quality for drinking purposes was estimated in study area for both months. The values of EWQI map ranged from 111.74 to 175.47, with mean value of 149.47 in August, 2018, while, in February, 2019, they were found between 113.02 and 189.08, with mean value of 147.26. The results revealed that groundwater quality is classified as moderate to poor.

According to the spatial distribution maps of EWQI, the value of this index was lower in eastern parts than western parts and the classified maps clearly depicted two moderate and poor zones in August, 2018, and February, 2019 (Fig 6). These maps represented that the groundwater quality changes from Moderate class in the west to "Poor" class in the east. The comparison of the classified EWQI maps of two months showed that the quality of groundwater for drinking purpose become a little bit better in south parts, while in the north parts it was a little deteriorated. This is also consisting with the hydraulic slope of the area as groundwater moves from northwest to southeast. Groundwater in 275.57 Km^2 area (37.62 %) in August and 358.65 Km^2 area (48.96 %) in February had moderate quality, while 456.94 Km^2 area (62.38 %) in August and 373.86 Km^2 area (51.04%) in February had poor quality.

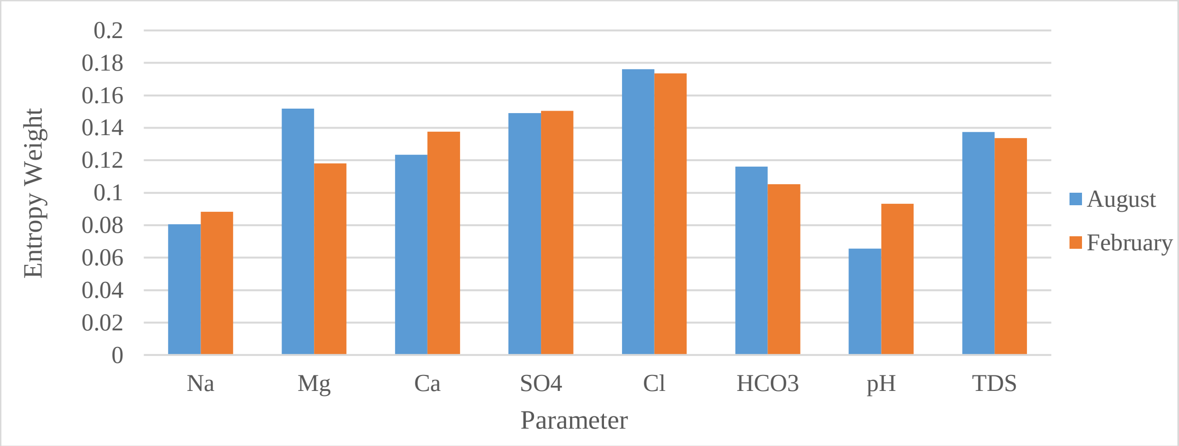

Fig. 5. The entropy weight of physicochemical parameters

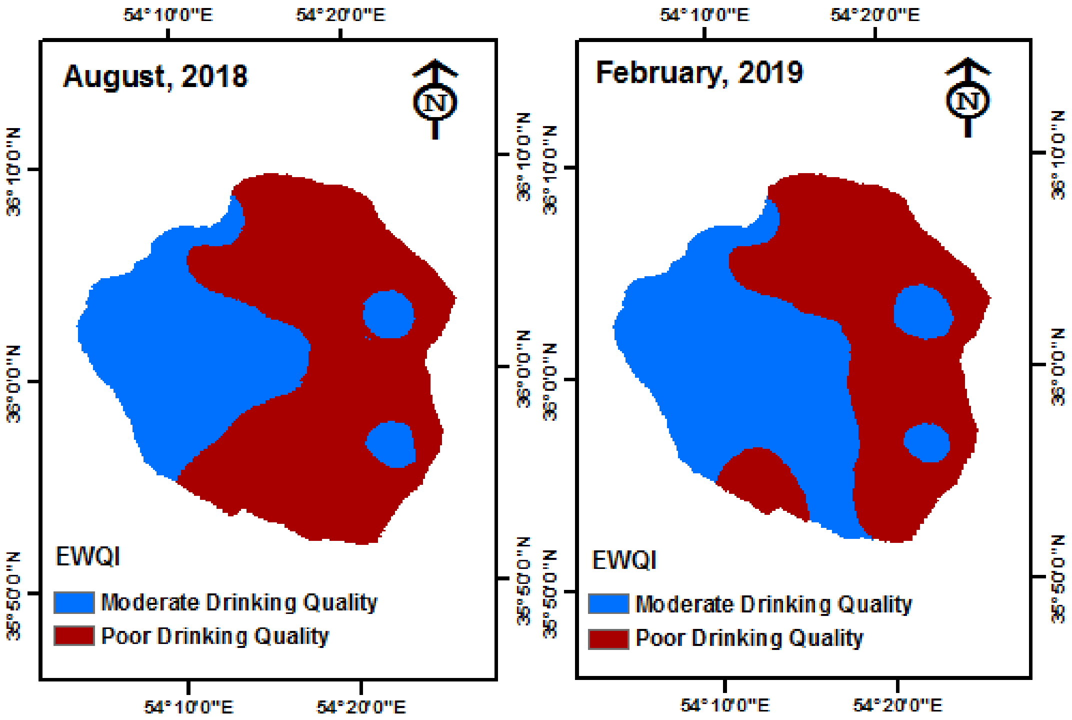

Fig. 6. Spatial distribution maps of drinking water quality based on EWQI

3.3. Groundwater Quality for Irrigation Purposes

The suitability of groundwater quality for irrigation purpose in the region was assessed using SAR, MH, KR, SH, K, PS, TDS, Cl$^-$, PI, SSP indices. Physicochemical parameters of groundwater were adopted to calculate these indices and the spatial distribution maps of indices developed by Geographic Information System (GIS) based on IDW spatial analysis technique (Fig 7).

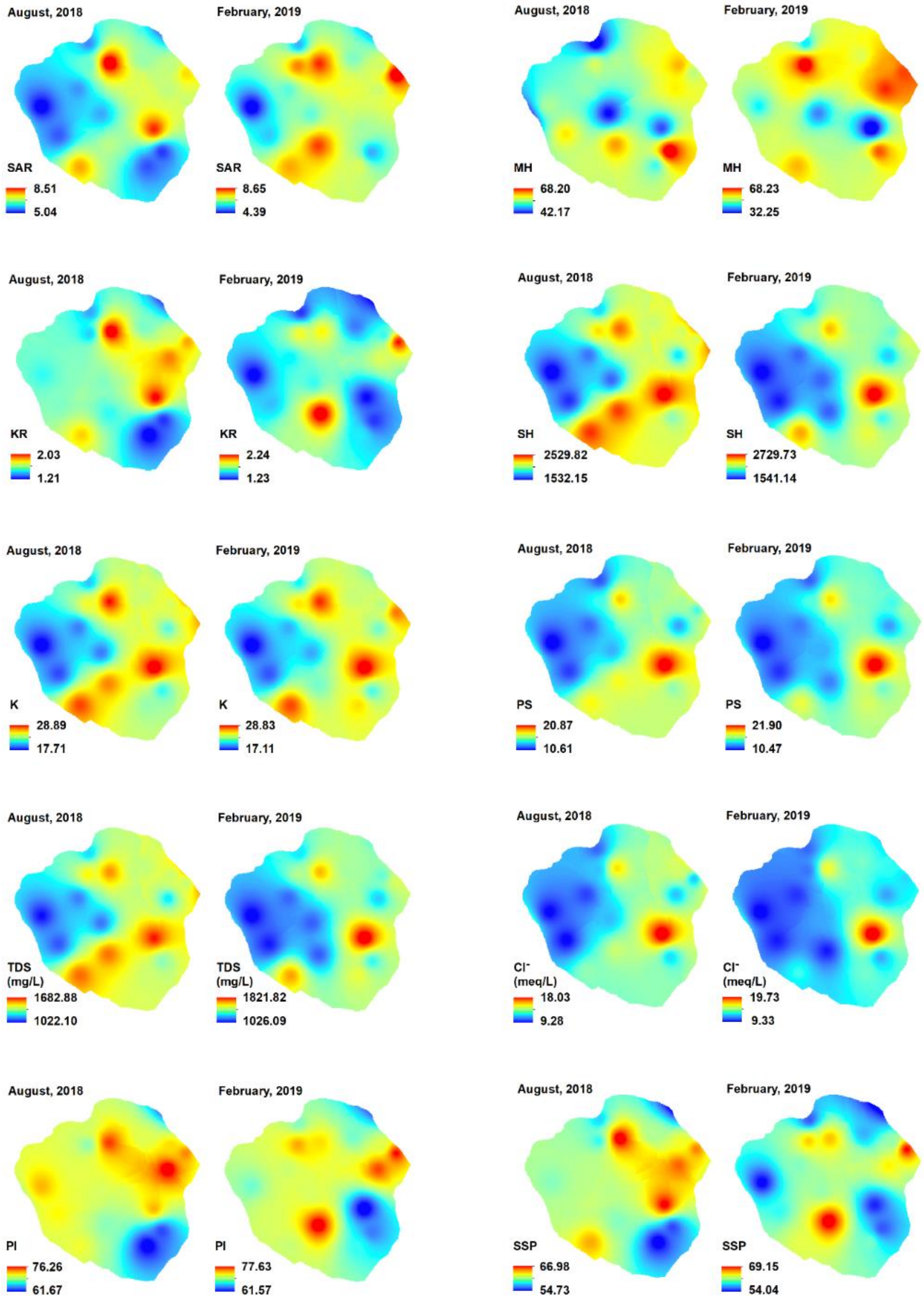

Fig. 7. Maps of groundwater quality indices for irrigation purpose

Sodium Adsorption Ratio

SAR shows the sodicity hazard and if water has high concentration of sodium and calcium, it may change the structure of the soil (Adimalla, 2020). According to the results, SAR values ranged from 5.04 to 8.51 in August, 2018, and from 4.39 to 8.65 in February, 2019. Groundwater in all samples was categorized into “Excellent” class in both months (Table 5). The average of SAR values in these months are 6.37 and 6.41. These maps represented that SAR values totally are higher in eastern parts of the study area than western parts in both month (Fig 7).

Table 5. Groundwater quality classification based on SAR (Ravikumar et al., 2011)

SAR	Groundwater Quality	Number of Samples (%)	
		August	February
< 10	Excellent	21 (100.00%)	21 (100.00%)
10 - 18	Good	0 (0.00%)	0 (0.00%)
15 - 26	Injurious	0 (0.00%)	0 (0.00%)
26 <	Unsuitable	0 (0.00%)	0 (0.00%)

Magnesium Hazard

Magnesium normally exchanges with sodium in the irrigated soil (Keesari *et al*., 2016) and its high concentration increases the soil aggregation (Zhou *et al*., 2020). The results showed that 4 samples in August and 5 sample in February had groundwater which were classified into suitable class and groundwater in the rest of the samples were classified into unsuitable status (Table 6). The maps of MH presented that the groundwater in central parts of the plain had better conditions than northern and southern parts in terms of this index. The mean value of MH during the study period decreased from 54.43 to 52.61.

Table 6. Groundwater quality classification based on Magnesium Hazard (Szabolcs, 1964)

MH (%)	Groundwater Quality	Number of Samples (Percent)	
		August	February
< 50	Suitable	4 (19.00%)	5 (24.00%)
50 <	Unsuitable	17 (81.00%)	16 (76.00%)

Kelley's Ratio

KR is defined to determine the concentration of sodium against the concentration of magnesium and calcium (Gaikwad *et al*., 2020). The results indicated that the most of the groundwater samples (90.50%) were categorized into unsuitable class in both months and only 2 groundwater samples (9.50%) had suitable condition (Table 7). The maps of this index represented KR value in August is higher in west and in February in south and its value a little increased from 1.58 to 1.59 from August, 2018, to February, 2019.

Table 7. Groundwater quality classification based on Kelley's Ratio (Kelley, 1963)

KR	Groundwater Quality	Number of Samples (Percent)	
		August	February
< 1	Suitable	2 (9.50%)	2 (9.50%)
1 <	Unsuitable	19 (90.50%)	19 (90.50%)

Salinity Hazard (SH)

Salinity is one of the most crucial parameter which uses to distinguish the groundwater quality for irrigation and determines the existence of salt in groundwater, which its high concentration can affect on osmotic process of plants (Subramani *et al*., 2005). SH index value ranged between 1532.15 and 2529.82 in August, and between 1541.14 and 2729.73 in February. In August, groundwater was classified into "Doubtful" class in 15 samples, while in 6 samples was classified into "Unsuitable" class and in February, groundwater was classified into

“Doubtful” class in 15 samples and “Unsuitable” class in 5 samples (Table 8). The average values of SH in August and February were 2036.99 and 1996.70, respectively. These maps indicated that the SH values were lower in western parts of the study area than eastern parts in both month (Fig 7).

Table 8. Groundwater quality classification based on Salinity Hazard (Tahmasebi *et al*., 2018)

EC($\boldsymbol{\mu}$mohs/cm)	Groundwater Quality	SH Class	Number of Samples (Percent)	
			August	February
< 250	Excellent	C1	0 (0.00%)	0 (0.00%)
250–750	Good	C2	0 (0.00%)	0 (0.00%)
750–2250	Doubtful	C3	15 (71.00%)	16 (76.00%)
2250 <	Unsuitable	C4	6 (29.00%)	5 (24.00%)

Synthetic Harmful Coefficient

Synthetic Harmful Coefficient mainly indicates the salt and alkalis hazards (Xu *et al*., 2019). Based on the results, the groundwater in the most samples had excellent condition (15 samples in both months). The maps of this index showed that the value of K was higher in eastern parts than western parts, with average value of 23.20 in August and 22.91 in February (Fig 7).

Table 9. Groundwater quality classification based on Synthetic Harmful Coefficient (Zhou *et al*., 2009)

K	Groundwater Quality	Number of Samples (Percent)	
		August	February
< 25	Excellent	15 (71.00%)	15 (71.00%)
25 - 36	Good	5 (24.00%)	6 (29.00%)
36 - 44	Injurious	1 (5.00%)	0 (0.00%)
44 <	Unsuitable	0 (0.00%)	0 (0.00%)

Potential Salinity

PS index is primarily related to the content of chloride and sulfate. The total groundwater samples were within injurious to unsatisfactory class in both month based on PS values, which ranged from 10.61 to 20.87 (with an average of 14.93) in August and from 10.47 to 20.90 (with an average of 14.65) in February. In both months the values were higher in southeastern than other parts (Fig 7).

Total Dissolved Solids

TDS estimates the total organic and inorganic substances which are dissolved in water (Pan *et al*., 2019). That the groundwater in all samples was classified within slightly saline class in both months and the maps illustrated that TDS value were found from 1022.10 1682.88 mg/L in August and from 1026.09 to 1821.82 mg/L in February. The TDS value was totally higher in eastern parts than other parts in both months (Fig 7).

Chloride

Chloride may originate from various sources such as weathering, seawater infiltration and leaching of sedimentary rocks (Rout and Sharma, 2011). High concentration of this anion can be a sign of excessive organic pollution (Yogendra and Puttaiah, 2008). The results indicated the groundwater in all samples was categorized into brackish class in both months (Table 12). The western parts had lower value of Cl^- than eastern parts in both months (Fig 7) and mean value of Cl^- was 12.42 meq/L and 12.26 meq/L in August and February, respectively.

Table 10. Groundwater quality classification based on Potential Salinity (Doneen, 1962)

PS (meq/L)	Groundwater Quality	Number of Samples (Percent)	
		August	February
< 3	Excellent to Good	0 (0.00%)	0 (0.00%)
3 – 5	Good to Injurious	0 (0.00%)	0 (0.00%)
5 <	Injurious to Unsatisfactory	21 (100.00%)	21 (100.00%)

Table 11. Groundwater classification based on Total Dissolved Solids (Davis and DeWiest, 1966)

TDS (mg/L)	Groundwater Class	Number of Samples (Percent)	
		August	February
< 1000	Non Saline	0 (0.00%)	0 (0.00%)
1000 – 3000	Slightly Saline	21 (100.00%)	21 (100.00%)
3000 – 10000	Moderately Saline	0 (0.00%)	0 (0.00%)
10000 <	Very Saline	0 (0.00%)	0 (0.00%)

Table 12. Classification of groundwater based on Chloride (Stuyfzand, 1989)

Ranges (meq/L)	Categories	Number of Samples (Percent)	
		August	February
< 0.14	Extremely Fresh	0 (0.00%)	0 (0.00%)
0.14 – 0.85	Very Fresh	0 (0.00%)	0 (0.00%)
0.85 – 4.23	Fresh	0 (0.00%)	0 (0.00%)
4.23 – 8.46	Fresh Brackish	0 (0.00%)	0 (0.00%)
8.46 – 28.21	Brackish	21 (100.00%)	21 (100.00%)
28.21 – 282.06	Brackish - Salt	0 (0.00%)	0 (0.00%)
282.06 – 564.13	Salt	0 (0.00%)	0 (0.00%)
564.13 <	Hypersaline	0 (0.00%)	0 (0.00%)

Permeability Index

Irrigation water can affect the soil permeability in long term (Ramesh and Elango, 2012). The results of PI showed that groundwater in most samples ranged between 25 and 75 (class II) (Table 13). In both months, PI value was lower in southeastern than other parts (Fig 7) and its mean value increased from 69.61 to 70.02 during the study period.

Table 13. Groundwater quality classification based on Permeability Index (Doneen, 1964)

PI (%)	Groundwater Quality	Class	Number of Samples (Percent)	
			August	February
75 <	Suitable	Class I	1 (5.00%)	3 (14.00%)
25 – 75	Suitable	Class II	20 (95.00%)	18 (86.00%)
< 25	Unsuitable	Class III	0 (0.00%)	0 (0.00%)

Soluble Sodium Percentage

SSP is an important index for assessing the sodium hazard and shows the dominant of sodium to the total cations (Peiyue *et al*., 2011). 19 groundwater samples were classified into unsuitable class (Table 14) and its value was totally higher in central parts than other parts in both months (Fig 7) and its mean value increased from 60.83 to 60.93 from August, 2018, to February, 2019.

Table 14. Groundwater quality classification based on Soluble Sodium Percentage (Wani *et al*., 2014)

SSP	Groundwater Quality	Number of Samples (Percent)	
		August	February
< 50	Suitable	2 (9.50)	2 (9.50)
50 <	Unsuitable	19 (90.50)	19 90.50)

3.4. Groundwater table changes and Land Use Land Cover

Groundwater table changes map was produced to show the changes in groundwater table during study period and its effect on groundwater quality using groundwater table data. Changes of groundwater table during the study period were investigated using groundwater table data for two studied month. The map of groundwater level fluctuations (Fig 8, Left) illustrated that groundwater table decreased in the northern parts of the region, while in the southern parts has increased from August, 2018, to February, 2019. The changes of groundwater table range from -0.69 to +0.32 meter, with the average of -0.19 meter, which generally indicates the groundwater table depletion in south of the plain during study period.

For better understanding the suitability of groundwater, which provides the required water for different types of land use, the Land Use/Land Cover (LULC) map was generated by LULC map of Natural Resources and Watershed Management Organization of Iran (Fig 8, Right). According to this map, the most part of plain is bareland (56.8%) and followed by agricultural lands (15.85%), poor range (12.29%), urban area (9.02%), saltland (3.99%), and agriculture-fallow (2.05%) (Table 15). Saltland area is located in the east side of the plain and rangeland is in the north and west side and bareland is between them, which indicate that natural vegetation is decreasing from west to east. Due to the presence of saltland in the east side the amount of salinity is higher in this area, and value of EC, SAR KR and PS indices is higher.

4. Discussion

In the present study, EWQI, as a novel method, and various physicochemical indices were employed through GIS to determine the groundwater suitability for drinking and irrigation purposes, respectively.

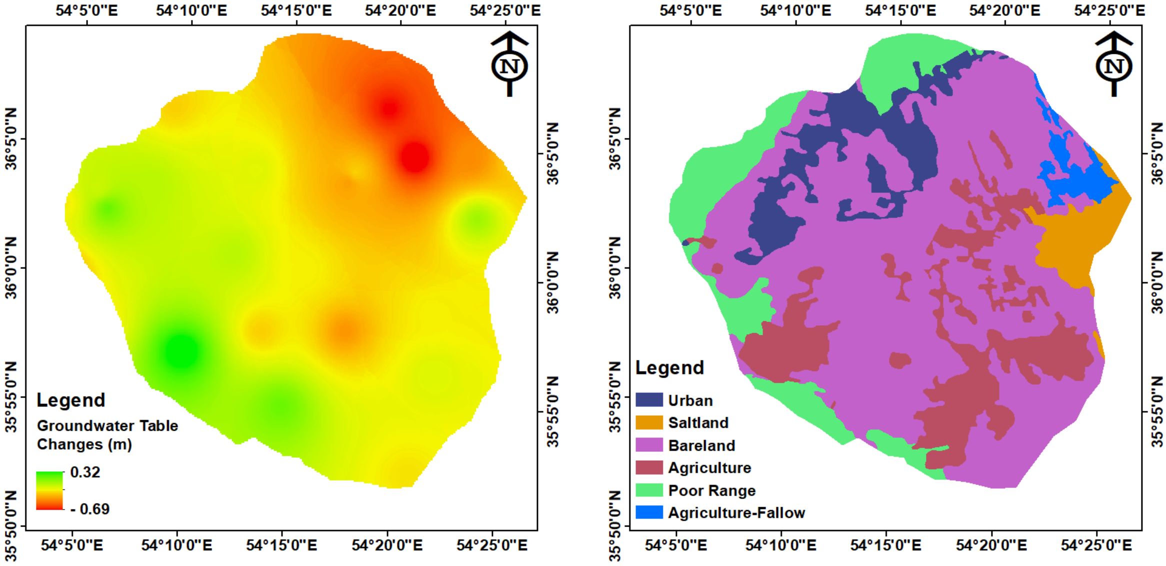

Fig. 8. The maps of groundwater table changes from August, 2018 to February, 2019 (Left) and LULC for Damghan Plain (Right)

Table 15. Area of LULC types in Damghan Plain

LULC Type	Area (Km^2)	Area (%)
Urban	66.05	9.02
Saltland	29.23	3.99
Bareland	416.06	56.8
Agriculture	116.14	15.85
Poor Range	90.01	12.29
Agriculture-Fallow	15.02	2.05
Sum	732.51	100.00

The initial study of groundwater characteristics represented that Na^+ and Cl^- have the highest concentrations in groundwater among cations and anions, respectively, and are exceeding the permissible limits of WHO standards in both months August, 2018, and February, 2019. Moreover, the strong relationship between these two ions based on bivariate diagram reflected salinity status of groundwater. On the other hand, the relationship between other cations and anions are weaker than their relationship. Despite this issue along with high levels of TDS, precautions should be taken for drinking. Additionally, groundwater quality for salinity-sensitive crops is poor and plants which are more resistant to salinity should be cultivated in the studied plain.

The results of evaluation of groundwater quality using the EWQI highlighted that among the all parameters, Cl^- has the highest entropy weight in both months which indicated this ion has the highest effect on groundwater quality and less changes. EWQI maps implied groundwater totally had moderate status in west and poor status in east of the area. The mean value of this index become a little lower from 149.47 in August to 147.26 in February, which reflected that the groundwater quality has not changed much and has just slightly improved for drinking purpose. The reason of this decreasing can be increasing the groundwater level in the southern parts of the area, which shows that with the decrease of groundwater level, its quality decreased and in the southern parts, with the increase of groundwater level (increase of groundwater quantity), its quality slightly increased.

The assessment of groundwater quality for irrigation showed that although SAR, KR, PI and SSP indices had slightly increased in their mean value, but groundwater is suitable in terms of SAR, K and PI in both months and has not limitation for using in agricultural sectors. This result indicates that the concentration of Na^+ was more appropriate than other ions used in these indices. Conversely the groundwater has not good status in terms of SSP, MH, SH, K, PS, TDS and Cl^- indicating groundwater has high concentration of solid materials and other ions.

The evaluation of groundwater suitability for irrigation purposes revealed that SAR, KR, PI and SSP indices had slightly increased in their mean value, which indicated the groundwater quality become worse in terms of these indices. On the other hand, the mean value of MH, SH, K, PS, TDS and Cl^- indices have slight decrease during the study period. SH, PS and Cl^- values in the southern parts have been increased from August to February. This can be due to rising groundwater table.

LULC map was employed to show which groundwater consumption is appropriate with its quality. This map indicated that the most urban areas were located in the north parts, in which groundwater has both moderate and poor quality, in west side has moderate quality while in east side has poor quality. Agricultural lands are located in the middle and south of the plain, in which the groundwater has mainly suitable quality in terms of SAR, K and PI and unsuitable in terms of MH, KR, SH, PS, TDS, Cl^- and SPP. The suitable condition in terms of SAR, K and PI is due to the high concentration of Mg^{2+} and Ca^{2+} (Table 4). Thus, groundwater is not suitable for irrigation in agriculture sector.

5. Conclusion

The results of groundwater quality for drinking purpose showed that Cl- has the most effect on its quality and has less change among all used physicochemical parameters. Base on EWQI, the quality of groundwater is totally moderate in western parts of Damghan Plain, while in the eastern parts it has poor status. The evaluation of groundwater suitability for irrigation purposes revealed that SAR, KR, PI and SSP indices had slightly increased in their mean value, which indicated the groundwater quality become worse in terms of these indices. On the other hand, the mean value of MH, SH, K, PS, TDS and Cl- indices have slight decrease during the study period. SH, PS and Cl- values in the southern parts have been increased from August to February. This can be due to rising groundwater table.

The results of the present study provide guidance to decide for appropriate management. It is recommended that relevant organizations adopt the suitable strategies to save by sustainable use and to enhance the quality of groundwater in Damghan Plain to make more usable the groundwater and which is mainly used for agricultural purposes.

References

Adimalla, N., 2020. Controlling factors and mechanism of groundwater quality variation in semiarid region of South India: an approach of water quality index (WQI) and health risk assessment (HRA). Environmental Geochemistry and Health, 42(6); 1-28.

Adimalla, N., 2021. Application of the Entropy Weighted Water Quality Index (EWQI) and the Pollution Index of Groundwater (PIG) to Assess Groundwater Quality for Drinking Purposes: A Case Study in a Rural Area of Telangana State, India. Archives of Environmental Contamination and Toxicology, 80(1); 31-40.

Amiri, V., M. Nakhaei, N. Sohrabi, 2013. Evaluating the Groundwater Quality Variations Using Factor Analysis Combined with Information Entropy Theory. Advanced Applied Geology, 3(1); 31-39.

Amiri, V., M. Rezaei, N. Sohrabi, 2014. Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. Environmental Earth Sciences, 72(9); 3479-3490.

Arabameri, A., J. Roy, S. Saha, T. Blaschke, O. Ghorbanzadeh, D. Tien Bui, 2019. Application of Probabilistic and Machine Learning Models for Groundwater Potentiality Mapping in Damghan Sedimentary Plain, Iran. Remote Sensing, 11(24); 3015.

Asghari Moghaddam, A., M. Vadiati, 2016. Groundwater Quality Ranking of Sarab Plain for Drinking Purpose Using Entropy Method. Water and Soil Science, 26(3); 1-13.

Ashtiani, G., M. Mahdavi, A. Malekian, B. Motamedvaziri, 2016. Groundwater modeling for estimation of the recharge rate and identification of appropriate recharge sites in Damghan Plain, Iran. Caspian Journal of Environmental Sciences. 14(2); 139-153.

Davis, S.N., R.J. DeWiest, 1966. Hydrogeology.

Doneen, L.D., 1962. The Influence of Crop and Soil on Percolating Water. 156–163.

Doneen, L.D., 1964. Water quality for agriculture. Department of Irrigation, University of California, Davis. 48.

Dos Santos Simões, F., A.B. Moreira, M.C. Bisinoti, S.M.N. Gimenez, M.J.S. Yabe, 2008. Water quality index as a simple indicator of aquaculture effects on aquatic bodies. Ecological indicators, 8(5); 476-484.

Egbueri, J.C., P.D. Ameh, C.O. Unigwe, 2020. Integrating entropy-weighted water quality index and multiple pollution indices towards a better understanding of drinking water quality in Ojoto area, SE Nigeria. Scientific African, 10; e00644.

Ememu, A. H. Nwankwoala, 2018. Application of Water Quality Index (WQI) For Agricultural and Irrigatio nal Use Around Okpoko, Southeastern Nigeria. Engineering Heritage Journal (GWK), 2(1); 14-18.

Feng, Y., Y. Fanghui, C. Li, 2019. Improved entropy weighting model in water quality evaluation. Water Resources Management, 33(6); 2049-2056.

Gaikwad, S., S. Gaikwad, D. Meshram, V. Wagh, A. Kandekar, A. Kadam, 2020. Geochemical mobility of ions in groundwater from the tropical western coast of Maharashtra, India: implication to groundwater quality. Environment, Development and Sustainability, 22(3); 2591-2624.

Ghazaryan, K., H. Movsesyan, H. Khachatryan, A. Yezekyan, 2019. Hydrochemical Analysis and Evaluation of Groundwater Quality for Irrigation in Masis Region, Armenia. Chemistry and Biology, 53(3); 193-199.

Gnanachandrasamy, G., C. Dushiyanthan, T.J. Rajakumar, Y. Zhou, 2020. Assessment of hydrogeochemical characteristics of groundwater in the lower Vellar river basin: using Geographical Information System (GIS) and Water Quality Index (WQI). Environment, development and sustainability, 22(2); 759-789.

Gorgij, A.D., O. Kisi, A.A. Moghaddam, A. Taghipour, 2017. Groundwater quality ranking for drinking purposes, using the entropy method and the spatial autocorrelation index. Environmental earth sciences, 76(7); 269.

He, X., J. Wu, S. He, 2019. Hydrochemical characteristics and quality evaluation of groundwater in terms of health risks in Luohe aquifer in Wuqi County of the Chinese Loess Plateau, northwest China. Human and Ecological Risk Assessment: An International Journal, 25(1-2); 32-51.

Jain, C., U. Vaid, 2018. Assessment of groundwater quality for drinking and irrigation purposes using hydrochemical studies in Nalbari district of Assam, India. Environmental earth sciences, 77(6); 254.

Kahsay, G.H., T. Gebreyohannes, F.W. Tesema, T.A.G. Emabye, 2019. Evaluation of Groundwater Quality and Suitability for Drinking and Irrigation Purposes Using Hydrochemical Approach: The Case of Raya Valley, Northern Ethiopia. Momona Ethiopian Journal of Science, 11(1); 70-89.

Kawo, N.S. S. Karuppannan, 2018. Groundwater quality assessment using water quality index and GIS technique in Modjo River Basin, central Ethiopia. Journal of African Earth Sciences, 147; 300-311.

Keesari, T., K. Ramakumar, S. Chidambaram, S. Pethperumal, R. Thilagavathi, 2016. Understanding the hydrochemical behavior of groundwater and its suitability for drinking and agricultural purposes in Pondicherry area, South India–a step towards sustainable development. Groundwater for Sustainable Development, 2-3; 143-153.

Kelley, W., 1963. Use of saline irrigation water. Soil science, 95(6); 385-391.

Kumari, M. S. Rai, 2020. Hydrogeochemical Evaluation of Groundwater Quality for Drinking and Irrigation Purposes Using Water Quality Index in Semi Arid Region of India. Journal of the Geological Society of India, 95(2); 159-168.

Li, P., R. Tian, C. Xue, J. Wu, 2017. Progress, opportunities, and key fields for groundwater quality research under the impacts of human activities in China with a special focus on western China. Environmental Science and Pollution Research, 24(15); 13224-13234.

Liu, F., Z. Zhao, L. Yang, Y. Ma, B. Li, L. Gong, H. Liu, 2020. Phreatic Water Quality Assessment and Associated Hydrogeochemical Processes in an Irrigated Region Along the Upper Yellow River, Northwestern China. Water, 12(2); 463.

Manoj, S., M. Thirumurugan, L. Elango, 2017. An integrated approach for assessment of groundwater quality in and around uranium mineralized zone, Gogi region, Karnataka, India. Arabian Journal of Geosciences, 10(24); 557.

Maskooni, E.K., M. Naseri-Rad, R. Berndtsson, K. Nakagawa, 2020. Use of heavy metal content and modified water quality index to assess groundwater quality in a semiarid area. Water, 12(4); 1115.

Nair, H.C., D. Padmalal, A. Joseph, 2015. Hydrochemical assessment of tropical springs - a case study from SW India. Environmental monitoring and assessment, 187(2); 48.

Oki, A. T. Akana, 2016. Quality assessment of groundwater in Yenagoa, Niger delta, Nigeria. Geosciences, 6(1); 1-12.

World Health Organization (WHO), 2011. Guidelines for drinking water quality.

Pan, C., Ng, K.T.W., Fallah, B. and Richter, A. 2019. Evaluation of the bias and precision of regression techniques and machine learning approaches in total dissolved solids modeling of an urban aquifer. Environmental Science and Pollution Research 26(2); 1821-1833.

Parhizkar, S., K. Ajdari, G.A. Kazemi, S. Emamgholizadeh, 2015. Predicting water level drawdown and assessment of land subsidence in Damghan aquifer by combining GMS and GEP models. Geopersia, 5(1); 63-80.

Pei-Yue, L., Q. Hui, W. Jian-Hua, 2010. Groundwater quality assessment based on improved water quality index in Pengyang County, Ningxia, Northwest China. E-Journal of Chemistry, 7(S1); S209-S216. .

Peiyue, L., W. Jianhua, Q. Hui, 2010. Groundwater quality assessment based on entropy weighted osculating value method. International Journal of Environmental Sciences, 1(4); 621-630.

Peiyue, L., W. Qian, W. Jianhua, 2011. Groundwater suitability for drinking and agricultural usage in Yinchuan Area, China. International journal of Environmental sciences, 1(6); 1241-1249.

Prasanth, S.S., N. Magesh, K. Jitheshlal, N. Chandrasekar, K. Gangadhar, 2012. Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. Applied Water Science, 2(3); 165-175.

Ramesh, K. L. Elango, 2012. Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India. Environmental monitoring and assessment, 184(6); 3887-3899.

Ravikumar, P., R. Somashekar, M. Angami, 2011. Hydrochemistry and evaluation of groundwater suitability for irrigation and drinking purposes in the Markandeya River basin, Belgaum District, Karnataka State, India. Environmental monitoring and assessment, 173(1-4); 459-487.

Rostami, A.A., M. Isazadeh, M. Shahabi, H. Nozari, 2019. Evaluation of geostatistical techniques and their hybrid in modelling of groundwater quality index in the Marand Plain in Iran. Environmental Science and Pollution Research, 26(34); 34993-35009.

Rout, C. A.Sharma, 2011. Assessment of drinking water quality: A case study of Ambala cantonment area, Haryana, India. International journal of environmental sciences, 2(2); 933-945.

Schriks, M., M.B. Heringa, M.M. Van Der Kooi, P. De Voogt, A.P. Van Wezel, 2010. Toxicological relevance of emerging contaminants for drinking water quality. Water research, 44(2); 461-476.

Shannon, C.E., 1948. A mathematical theory of communication. The Bell system technical journal, 27(3); 379-423.

Sharma, D.A., M.S. Rishi, T. Keesari, 2017. Evaluation of groundwater quality and suitability for irrigation and drinking purposes in southwest Punjab, India using hydrochemical approach. Applied Water Science, 7(6); 3137-3150.

Singh, K.K., G. Tewari, S. Kumar, 2020. Evaluation of Groundwater Quality for Suitability of Irrigation Purposes: A Case Study in the Udham Singh Nagar, Uttarakhand. Journal of Chemistry, 2020; 1-15.

Singh, K.R., R. Dutta,A.S. Kalamdhad, B. Kumar, 2019. Information entropy as a tool in surface water quality assessment. Environmental Earth Sciences, 78(1); 15.

Stuyfzand, P.J., 1989. Nonpoint source of trace element in potable groundwater in Netherland. Proceedings 18th TWSA Water Workings. Testing and Research Institute, KIWA. 3; 150-164.

Subramani, T., L. Elango, S. Damodarasamy, 2005. Groundwater quality and its suitability for drinking and agricultural use in Chithar River Basin, Tamil Nadu, India. Environmental Geology, 47(8); 1099-1110.

Szabolcs, I. 1964. The influence of irrigation water of high sodium carbonate content on soils. Agrokémia és talajtan, 13; 237-246.

Tahmasebi, P., M.H. Mahmudy Gharaie, F. Ghassemzadeh, A. Karimi Karouyeh, 2018. Assessment of groundwater suitability for irrigation in a gold mine surrounding area, NE Iran. Environmental Earth Sciences, 77(22); 766.

Ukah, B., P., Ameh, J., Egbueri, C. Unigwe, O. Ubido, 2020. Impact of effluent-derived heavy metals on the groundwater quality in Ajao industrial area, Nigeria: an assessment using entropy water quality index (EWQI). International Journal of Energy and Water Resources, 4(3); 1-14.

Venkateswaran, S., M.V. Prabhu, M.M. Rafi, K. Vallel, 2011. Assessment of groundwater quality for irrigational use in Cumbum valley, Madurai district, Tamilnadu, India. Nature, Environment and Pollution Technology, 10(2); 207-212.

Verma, A., B.K. Yadav, N. Singh, 2020. Hydrochemical monitoring of groundwater quality for drinking and irrigation use in Rapti Basin. SN Applied Sciences, 2(3); 1-15.

Wang, D., J. Wu, Y. Wang, Y. Ji, 2019. Finding high-quality groundwater resources to reduce the hydatidosis incidence in the Shiqu County of Sichuan Province, China: analysis, assessment, and management. Exposure and Health, 12; 1-16.

Wani, R.A., A.H. Mir, A. Tanveer, A. Jehangir, A. Yousuf, 2014. Preliminary study on irrigational quality of some ground water sources of Kashmir, India. International Journal of Scientific & Engineering Research, 5(2); 318-323.

Wijnen, M., B. Augeard, B. Hiller, C. Ward, P. Huntjens, 2012. Managing the invisible: Understanding and improving groundwater governance.

Xu, P., W. Feng, H. Qian, Q. Zhang, 2019. Hydrogeochemical characterization and irrigation quality assessment of shallow groundwater in the central-western Guanzhong basin, China. International journal of environmental research and public health, 16(9); 1492.

Yogendra, K., E.Puttaiah, 2008. Determination of water quality index and suitability of an urban waterbody in Shimoga Town, Karnataka, 346.

Zhou, J., B. Wu, Y. Wang, X.J. Guo, 2009. Distribution and quality assessment of medium salinity groundwater in plain areas in Tarim Basin, Xinjiang. China Rural Water Hydropower, 9; 32-36.

Zhou, Y., P. Li, M. Chen, Z. Dong, C. Lu, 2020. Groundwater quality for potable and irrigation uses and associated health risk in southern part of Gu’an County, North China Plain. Environmental Geochemistry and Health, 43; 1-23.

Zolekar, R.B., R.S. Todmal, V.S. Bhagat, S.A. Bhailume, M.S. Korade, S. Das, 2020. Hydrochemical characterization and geospatial analysis of groundwater for drinking and agricultural usage in Nashik district in Maharashtra, India. Environment, Development and Sustainability: A Multidisciplinary Approach to the Theory and Practice of Sustainable Development, 23; 1-20.

Appendix

Table 616: Data table of physicochemical parameters

Row	Month	UTM (X)	UTM (Y)	Na^+ (mg/lit)	Mg^{2+} (mg/lit)	Ca^{2+} (mg/lit)	SO_4^{2-} (mg/lit)	Cl^- (mg/lit)	HCO_3^- (mg/lit)	pH	TDS (mg/lit)
1	Aughust, 2018	236000	3986300	333.355	43.74	116.232	226.7016	529.2685	128.142	7.74	1341
2		240800	3989200	195.415	37.665	52.104	132.5628	328.976	192.213	7.9	1022
3		243800	3984200	223.2329	44.955	52.104	225.741	328.976	164.754	7.6	1088
4		247300	3992300	244.8435	44.955	64.128	218.0562	352.0185	164.754	7.46	1131
5		247700	3978500	366.4606	61.3575	80.16	398.649	456.596	170.856	7.59	1614
6		249100	3996600	317.262	65.61	84.168	279.5346	403.421	274.59	7.47	1467
7		249200	4000400	266.684	42.525	96.192	149.3733	367.971	305.1	7.89	1213
8		251400	3987900	251.9704	37.665	80.16	174.8292	401.6485	158.652	7.82	1121
9		252700	3982300	340.9417	74.115	77.154	318.9192	483.1835	244.08	7.41	1607
10		252900	3997000	410.3715	58.32	80.16	273.2907	529.2685	256.284	7.39	1575
11		259000	3998100	314.5032	61.965	76.152	172.4277	474.321	274.59	7.5	1369
12		259800	3978600	280.7079	63.18	98.196	294.4239	454.8235	146.448	7.74	1387
13		260900	3985200	375.8865	46.17	90.18	272.8104	639.1635	134.244	7.24	1683
14		261200	4009400	375.6566	57.105	90.18	150.8142	573.581	302.049	7.58	1592
15		262300	3981100	254.2694	71.685	55.11	327.5646	412.2835	125.091	7.46	1310
16		263400	3992300	277.0295	46.17	54.108	155.6172	403.421	268.488	7.86	1226
17		264000	3996400	311.7444	60.75	65.13	146.4915	488.501	259.335	7.65	1382
18		265100	4004800	168.2868	72.9	79.158	139.7673	359.1085	216.621	7.54	1082
19		266600	3995100	333.355	53.46	72.144	277.1331	403.421	241.029	7.46	1375
20		266800	4004200	227.8309	70.47	94.188	200.7654	382.151	305.1	7.91	1305
21		269300	3998400	533.368	125.145	136.272	399.6096	917.446	265.437	7.49	2600
22	February, 2019	236000	3986300	325.7683	54.675	80.16	206.529	545.221	128.142	7.92	1392
23		240800	3989200	180.4715	35.235	70.14	109.9887	330.7485	213.57	7.41	1026
24		243800	3984200	235.8774	43.74	66.132	152.7354	345.6375	207.468	7.47	1060
25		247300	3992300	258.4076	48.6	65.13	226.7016	355.5635	186.111	7.78	1137
26		247700	3978500	364.6214	65.61	78.156	403.9323	454.8235	195.264	7.39	1614
27		249100	3996600	358.644	70.47	54.108	355.422	385.696	286.794	7.21	1395
28		249200	4000400	256.3385	46.17	94.188	126.3189	381.0875	326.457	7.95	1261
29		251400	3987900	256.7983	35.235	84.168	157.5384	408.7385	180.009	7.93	1130
30		252700	3982300	319.561	37.665	62.124	267.5271	344.9285	176.958	7.5	1126
31		252900	3997000	393.5888	61.965	82.164	250.2363	545.221	237.978	7.66	1590
32		259000	3998100	299.7896	59.535	88.176	171.9474	472.5485	298.998	7.71	1381
33		259800	3978600	325.7683	57.105	90.18	317.4783	469.7125	158.652	7.7	1479
34		260900	3985200	354.7357	47.9925	166.332	208.9305	699.4285	158.652	7.14	1822
35		261200	4009400	326.6879	55.89	117.234	177.2307	579.6075	320.355	7.83	1608
36		262300	3981100	255.8787	64.395	64.128	318.9192	411.22	155.601	7.78	1290
37		263400	3992300	271.9717	51.6375	48.096	134.9643	407.675	286.794	7.8	1235
38		264000	3996400	308.9856	61.3575	70.14	166.1838	451.2785	280.692	7.77	1320
39		265100	4004800	172.8848	68.04	94.188	200.2851	362.6535	241.029	7.63	1095
40		266600	3995100	400.026	61.965	60.12	311.2344	433.5535	280.692	7.37	1449
41		266800	4004200	225.7618	66.825	96.192	162.3414	389.241	298.998	7.21	1321
42		269300	3998400	366.2307	85.05	70.14	399.6096	506.226	286.794	7.86	1699